Available online at www.sciencedirect.com
SciVerse ScienceDirect
ELSEVIER
Procedia Environmental Sciences 7 (2011) 200–205
Procedia Environmental Sciences

Spatial Statistics Conference

Evolution of water quality around the Island of Borneo during the last 8-years

B. Oney[a*], A. Shapiro[b], M. Wegmann[c]
[a]Global Change Ecology, University of Bayreuth, Germany
[b]World Wildlife Fund for Nature, Berlin, Germany
[c]Department of Remote Sensing, Institute of Geography, University of Würzburg, Würzburg, Germany

Abstract

Water quality around the Island of Borneo is important for the coral reefs in Borneo's proximity. Sediment input into freshwater and marine ecosystems is a result of natural processes. However, mining, deforestation, poor agricultural practices can greatly increase sediment input into aquatic systems. According to time series analysis of the coastal waters around Borneo, water quality has worsened in the last 8 years. This short study analyzes and illustrates the particular year-to-year changes in the relevant waters using MERIS data from 2003-2010, as well as for the entire 8-year period. Changes in the statistical characteristics of the water surface variables, yellow substance (colored dissolved organic matter) and total suspended matter, in Borneo's coastal waters can be seen. The intra-annual variables derived include minimum, maximum, standard deviation and average. The interesting inter-annual variables investigated are slopes of the mentioned water quality characteristics over a period of 8 years around Borneo, which changed since 2003 and decreases for most of the Island of Bro. According to this study, further land development on the island of Borneo will further decrease water quality around Borneo and worsen conditions for coral reefs and other coastal ecosystems. This study also illustrates the utility and prowess of the open source programs BEAM, GRASS and R.

Selection and peer-review under responsibility of Spatial Statistics 2011

Keywords: remote sensing; water color; MERIS; environmental change; degradation

1. Introduction

Land cover changes are occurring on a global scale [e.g 1,2,3], as well as changes in water quality and coral reef degradation [4]. Coastal water integrity exhibits many pattern often related to pollution from run-off [5,6]. Remote sensing has broad applications and implications for conservation efforts, because it is a widely available source of quality data which can play an important role for environmental change

* Corresponding author: Brian Oney
E-mail address: brian.j.oney@gmail.com

Selection and peer-review under responsibility of Spatial Statistics 2011
doi:10.1016/j.proenv.2011.07.035

monitoring efforts, especially that of marine waters. Relatively recent developments in remote sensing technologies has led to improved ability to monitor and detect changes in ocean water color. The Envisat Medium Resolution Imaging Spectrometer (MERIS), which became operational in 2002 and offered fully global coverage starting 2003, offers five water color products, two of which were used in this study. Important for judging water quality, the reprocessed product bands total suspended matter (TSM, g m^{-3}) and colored dissolved organic matter (CDOM, m^{-1}), also known as yellow substance or gelbstoff, were investigated. Their utility lies in the ability to estimate turbidity and judge the trophic state of water, both of which are very important for marine ecosystems. It is also a good proxy for land-based water pollution.

1.1 Study region

This study investigated the evolution of water quality around Island of Borneo, the third largest island of the world and home to one of the richest terrestrial ecosystems, constituting the cornerstone of the important Indo-Malayan ecoregion [7]. Borneo's coasts also harbor one the richest marine ecosystems, bounding the so-called “coral triangle” in the northern coastal waters. Land-use change on Borneo is mainly related to increasing pulp production and oil palm agriculture [8]. The effects on land can be drastic and, when considering the carbon balance, even have global implications. Furthermore, the effects of deforestation and industrialization are important for downstream water integrity [5,6]. Water color data were summarized for the period 2003-2010 and investigated for changes over time, by means of linear regression. The land cover characteristics were investigated for their influence on the water quality directly off of the coast, starting at the river mouth.

2. Methods

MERIS imagery data (Reduced Resolution) provided by the European Space Agency (ESA) from the period 2003-2010 (389 images) were selected for least cloud cover.. Processing was done using the BEAM software [9]. The two reprocessed bands, TSM & CDOM were subset and pixel values were removed if they had a poor quality flag [10]. Subset images were subsequently imported in Geographic Resource Analysis Support System [11] (GRASS) for spatio-temporal analysis. The summary statistics and data handling was carried out in R [12] (R Core Development Team, 2010).

2.1 Analyses

Intra-annual analyses were performed for each year of the time series (mean, minimum, maximum, standard deviation). The result for each particular raster cell is a function of the cell value across the time-period (average of 48 partial images per year). The resulting intra-annual raster images were then taken and analyzed across all 8 years. A linear regression was performed on each set of intra-annual results to determine the behavior during the 8-year interannual period. Unfortunately, due to lack of data, more intricate analyses of the temporal behavior of these coastal waters was not allowed. The results from these time series analyses are merely indicatory.

Rectangular outflow sample polygons were created at the river mouth/outflow point of each major catchment extending perpendicularly to land, in order to consistently sample the potential downstream impact area from each watershed. Water color data within the polygons was extracted and averaged for each polygon. Each sample polygon corresponded to 250 raster cells with 1040m by 1160m resolution (1.46 km^2), equaling a total area of 364 km^2 per polygon.

Table 1. Summary of water characteristics over the 8 year period at catchments (n=44) illustrates the evolution of the water quality around Borneo. Note the range of characteristics.

	Total suspended matter (TSM)				*Colored dissolved organic matter (CDOM)*			
Statistic	**Min.**	**Median**	**Mean**	**Max.**	**Min.**	**Median**	**Mean**	**Max.**
8-year Mean	0.52	2.45	3.21	9.1	0.056	0.415	0.648	2.3
Slope of Mean	-0.34	-0.019	-0.0445	0.21	-0.033	0.0094	0.0231	0.19
Slope R^2 of Mean	0.056	0.145	0.176	0.42	0.08	0.16	0.174	0.47
y-intercept of Mean	0.59	2.45	3.36	10	0.035	0.385	0.564	2
8-year Mean of S.D.	0.99	5.6	6.85	17	0.15	1	1.54	4.4
Slope of S.D.	-1.5	-0.033	-0.135	0.47	-0.19	0.0115	0.0221	0.27
Slope R^2 of S.D.	0.063	0.13	0.168	0.5	0.086	0.15	0.151	0.31
y-intercept of S.D.	1.3	5.75	7.32	22	0.093	1.1	1.46	4.9
Mean of Max.	0.2	0.835	1.15	3.2	0.015	0.082	0.18	0.78
Slope of Max.	-0.39	-0.00325	-0.00826	0.14	-0.047	0.00215	0.0101	0.061
Slope R^2 of Max.	0.047	0.13	0.149	0.35	0.063	0.15	0.156	0.31
y-intercept of Max.	0.23	0.855	1.18	4.4	0.0036	0.0675	0.144	0.77
Mean of Min.	0.26	1.65	1.94	5.5	0.044	0.325	0.479	1.4
slope of Min.	-0.53	-0.016	-0.0368	0.22	-0.095	0.00345	0.00661	0.1
Slope R^2 of Min.	0.053	0.14	0.166	0.47	0.084	0.16	0.163	0.31
y-intercept of Min.	0.35	1.65	2.07	7.4	0.027	0.355	0.454	1.7

3. Results

The investigation of the yearly dynamics yielded many interesting maps of the studied water color bands. In Figure 1, values were extracted for each outlet polygon and averaged to investigate the state of the water quality of each affected outlet over the period of 2003-2010. Further inspection shows some spatial heterogeneity of the water quality at the outlets, but a general upward tendency for most river outlets. The proportion of bare soil was also displayed. This land cover characteristic has been shown to be a strong determinant, along with the erosivity factor and the potential soil loss (RUSLE) [14] of downstream CDOM on the Island of Borneo. Land cover data shown here are from [15]. For simplicity, all characteristics of the interannual linear regression results were sampled at the outlets, summarized and displayed in table 1.

3.1 Mean characteristics

The slopes of the averages of both CDOM and TSM are generally increasing but also show spatial heterogeneity, as indicated by the minimum values. The variation explained (R^2) is very heterogeneous, indicating presence of dynamics and some highly variable increases over time. Some catchments exhibit very high maximum 8-year mean values and correspondingly high y-intercepts, which is to be expected.

1.2 Standard deviation characteristics

Standard deviation of CDOM over the 8-year period exhibits a general increase in most catchments. The temporal evolution of the TSM standard deviation portrays a very dynamic behavior of outlet waters. Small coefficients of determination indicate high variability of the water color characteristics over time.

3.3 Maximum and minimum characteristics

The maximum of CDOM and TSM over the 8-year period shows a very dynamic environment as well, especially with TSM, with some outlets experiencing large increases and decreases of TSM over the 8-year period. The minimum CDOM results portray a stability of minimum values over the 8-years. However, the minimum TSM values exhibit some outliers of increasing and decreasing minimum values.

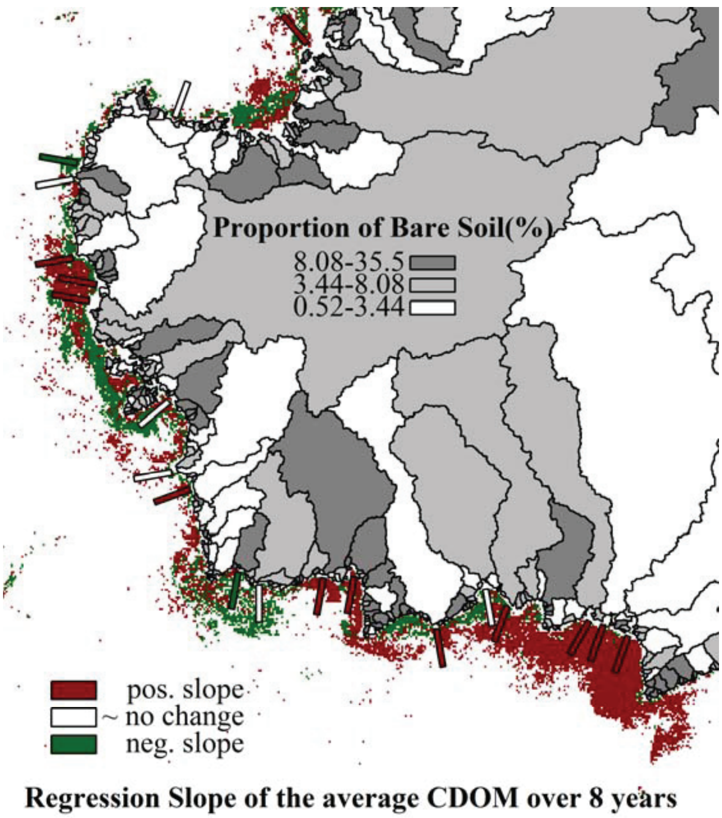

Figure 1. The slope of regression analysis of the average of the intra-annual colored dissolved organic matter (CDOM, m^{-1}) over a time period of 8 years (2003-2010). For simplicity, results were placed into three categories: negative slope (<-0.01), no slope (-0.01> slope <0.01), and positive slope (<0.01) (range is 0.33-0.19). The proportion of bare soil has been found to be an important determinant of CDOM in previous work, although no obvious symmetry can be observed. This figure shows the southwestern region of the Island of Borneo.

4. Discussion

Interestingly, many aspects of both CDOM and TSM are generally increasing with a few minor exceptions. CDOM is a very informative proxy for water quality. The presence of many large absolute values of slopes of water color attributes indicates the presence of very rapid (8-years) drastic environmental changes. Previous work by the authors [13] indicates that there is a very strong link between land use and coastal water quality. Figure 1 displays the spatial heterogeneity observed in coastal water quality. As there is a possibility of spatial structure there, spatial autocorrelation was investigated and found to be significant. However, analyses previously done [12] found no spatial structure in model residuals, indicating that the spatial structure in the water color was due to the similarity of near catchments.

The percentage of the outlets which increased over the past 8-years (table 2) indicates a general degradation of coastal water quality around most of the Island of Borneo and adds to the growing literature on large-scale effects of pollution in the Indo-Malayan ecoregion [e.g. 16]. The drivers of land use change also seem to be drivers of coastal water quality.

Table 2. Percent summary of the number of river outlets whose water quality (TSM and CDOM) decreased or increased during the 8 year period.

Statistic	Increased	Decreased
Maximum	0.523	0.477
Minimum	0.557	0.443
Average	0.545	0.455
Standard Deviation	0.534	0.466

Many conservation efforts are financially viable but poorly aimed. This study demonstrates the utility of remote sensing data to aide conservation efforts in developing countries, which tend to have a low sampling density and rapidly increasing human population. It also highlights the use of open source software in performing data analysis, and gives an example for conducting low-budget research with arguably the best analytical tools.

References

[1] Balmford, A., Bennun, L., ten Brink, B., Cooper, D., Côté, I. M., Crane, P., Dobson, A., Dudley, N., Dutton, I., Green, R. E., Gregory, R. D., Harrison, J., Kennedy, E. T., Kremen, C., Leader-Williams, N., Lovejoy, T. E., Mace, G., May, R., Mayaux, P., Morling, P., Phillips, J., Redford, K., Ricketts, T. H., Rodríguez, J. P., Sanjayan, M., Schei, P. J., van Jaarsveld, A. S. & Walther, B. A. (2005) The Convention on Biological Diversity's 2010 Target. Science, 307, 212-213.

[2] Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N. & Snyder, P. K. (2005) Global Consequences of Land Use. Science, 309, 570-575.

[3] Laurance, W. F., Lovejoy, T. E., Vasconcelos, H. L., Bruna, E. M., Didham, R. K., Stouffer, P. C., Gascon, C., Bierregaard, R. O., Laurance, S. G.,Sampaio, E., (2002) Ecosystem Decay of Amazonian Forest Fragments: a 22-Year Investigation. Cons. Biol. 16 (3), 605–618.

[4] Halpern, B.S., Walbridge, S., Selkoe, K. a, Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R. & Watson, R. (2008) A global map of human impact on marine ecosystems. Science, 319, 948-52.

[5] Edinger E.N., J. Jompa, G. V. Limmon, W. Widjatmoko, M.J. Risk (1998) Reef degradation and coral biodiversity in Indonesia: effects of land-based pollution, destructive fishing practices and changes over time. Mar. Pollut. Bull. 36:617–630

[6] Dosskey, Michael G., P. Vidon, N. P. Gurwick, C.J. Allan, T.P. Duval, and R. Lowrance, 2010. The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams. J. of the Am. Water Resources Asc. (JAWRA) 46:261-277.

[7] Olson, D. M., E. Dinerstein, E. D. Wikramanayake, N. D. Burgess, G. V. N. Powell, E. C. Underwood, J. A. D'Amico, I. Itoua, H. E. Strand, J. C. Morrison, C. J. Loucks, T. F. Allnutt, T. H.

Ricketts, Y. Kura, J. F. Lamoreux, W. W. Wettengel, P. Hedao, K. R. Kassem, 2001. Terrestrial Ecoregions of the World: A New Map of Life on Earth. BioScience 51:933-938.

[8] Ziegler S. and P. Weber, 2009. Das Schwinden der Tieflandregenwälder auf Borneo – Eine Untersuchung zum Lebensraumverlust des Borneo-Orang-Utans (Pongo pygmaeus). Zeitschrift des Kölner Zoos, 52nd yr.

[9] Brockmann Consulting GmbH, (2010) BEAM Software. <http://www.brockmann-consult.de/cms/web/beam/>

[10] European Space Agency 2006. MERIS Product Handbook. Issue 2.1

[11] Neteler M. and H. Mitasova, (2008) *Open Source GIS: A GRASS GIS Approach*. The International Series in Engineering and Computer Science: Volume 773. 406 pages, Springer, New York

[12] R Core Team. (2010) R: A language and environment for statistical computing. R Foundation for Statistical Computing Vienna Austria, 1.

[13] Oney, B., A. Shapiro, M. Wegmann, S. Dech. 2011. Land use change affects coastal water quality around Borneo. Proceedings of the International Symposium on Remote Sensing of the Environment. Sydney, Australia. *In press.*

[14] Renard, K. G. (1997). Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). USDA, Agricultural Research Service.

[15] Shapiro, A., J. Morrison, S. Wulfraat., 2011, Borneo Watershed Atlas. World Wildlife Fund for Nature Science Technical Report. *in press*.

[16] Todd, P.A., X Ong, L. M. Chou. (2010). Impacts of pollution on marine life in Southeast Asia. Biodivers. Conserv. 19:1063-1082

Acknowledgements

The authors wish to acknowledge the European Space Agency for providing the Envisat MERIS data, the R-Community, the GRASS community, and the BEAM developers for their support.

.